PERMANENT INTERNATIONAL ASSOCIATION

OF

CONGRESSES OF NAVIGATION

INLAND NAVIGATION

Reservoir Dams.
Conditions for the Construction and Employment of same.
Progress realised in their Construction.

REPORT

BY

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RESERVOIR DAMS

recently built in Italy with a view to feeding navigable canals

(Progress realised in their construction)

FIRST PART (Plate I)

GRAVITY DAMS (1)

BY

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I. — GENERAL REMARKS

Method of feeding Italian navigable canals.

The necessity of feeding navigable canals by means of reservoirs, formed by large dams, like many of those in existence in other countries, has not yet been felt in Italy. This is because the most important part of the system of inland navigation is developed in the valley of the Po, between the left bank of this river and the outlet of the great lakes, Garda, Como, Lugano and Maggiore, etc. and from this fact it is easy to feed the canals with the water flowing from these lakes, or with what comes from the rivers running down directly from the Alps, of which the glaciers, constituting real natural reservoirs of frozen water, supply water enough during the summer for the needs of navigation, as also for those of irrigation, the principal navigable canals serving for this purpose also in Italy.

(1) Report prepared for the XIIIth International Congress which should have taken place at Stockholm in 1915.

In the other regions of the country, the navigable canals are to be found at the outlets of the valleys of the Apennines, principally in the valleys of the Arno, the Tiber and the Reno, so that it is easy to feed them. These canals are, unfortunately, still in the state in which our ancestors left them and are at the present time of but little importance.

In order to improve them and to supply them with a greater quantity of water, such as modern navigation demands — a commencement has already been made — it will be necessary to provide for their feeding by constructing large dams to hold, in artificial lakes with a view to utilisation during summer, the winter floods, which are actually lost, or, what is still worse, form marshes in the plains. It will be necessary to have recourse to artificial lakes, because the water courses which come down from the Apennines, with very few exceptions, are very short of water during the summer, the Apennines not having glaciers and névés like the Alps.

The nocesssity of increasing the reserves of water in order to feed the canals.

Important undertakings are about to be commenced in Italy for the complete reorganisation of inland navigation according to modern ideas. The construction of large dams to form reservoirs in the high valley of the Arno, with a view to feeding the navigable way Florence-Pisa-Livourne has already been planned, as also for Lake Trasimeno, for the navigation of the Tiber, and in the high valleys of the Reno, the Enza and the Trebbia for the navigable canals on the right bank of the Po.

If however the question is still there, nevertheless numerous and important dams exist in Italy, either completed recently or in course of construction, which are destined to regulate and to utilise the water, as has been done in France and Germany especially, as well as in other countries.

These waters, instead of overflowing at the time of floods and being a source of danger as they are now by reason of the torrents which come from the above-mentioned rivers, could be utilised for producing motor-power, for irrigation and eventually also for internal navigation.

State subsidies for the construction of Dams.

The Italian Legislature already aids the construction of large dams for reservoirs by granting pecuniary subsidies. Quite recently an important subsidy was voted for the execution of important dams for the reservoirs of the Sila in Calabria, and of the Tyrse in Sardinia, which are destined to hold from 150 to 350 million cubic meters (195 to 455 million cubic yards) of water for the use of hydroelectric central stations of 150,000 and 20,000 HP, and for irrigation works, thanks to which regions now almost sterile, because of the want of water during eight months of the year, will be transformed into fertile ones.

At the present time Parliament is examining a proposed law to still further increase the state subsidy in favour of the construction of dams of this kind, of which the great importance is to-day recognised in Italy. With this contingency in view it may be useful to know what has been undertaken in the way of large dams, during the last few years, that is to say from 1900 to the present time, and also to know the ideas of Italian engineers on this subject.

The large dams constructed during the last ten years.

It must first of all be recognised that the populations of the valleys where a large dam must be constructed are generally very hostile to any project of the kind, for fear that if the work suddenly broke, which has already happened in other countries, but, very fortunately, not yet in Italy, it would cause serious floods and disasters with even the loss of human lives. In order to vanquish this hostility, which, for that matter, is easily accounted for, the only way is to demonstrate that the work to be undertaken has been so largely calculated and the precautions taken so great, that the dam will be stable and will resist every eventuality, not omitting earthquakes.

This is what has been usually done for the dams constructed during the last ten years in Italy, the only ones that will engage our attention here, all the more so because the less recent ones, such as the group of three old large dams of the Gorzente and those, of more modest dimensions, of the Cagliari aquaduct, of

the hydroelectric central-station of Cedra, of Tivoli and others besides, are all sufficiently well known and do not present any special particularity.

Neither shall we stop to examine the numerous little earthen dikes recently built on the Plaisance and Alexandria territories, nor the masonry dams built in the valleys of the Apennines, of Liguria and Calabria, the principal object of all of these being the supply of motor-power or of irrigation works and they do not present any technical interest.

We shall also leave on one side the works which the Government has sanctioned recently, and which will soon be put into execution, namely the dams of puddled earth on the Trebbia near to Bobbio, on the Sangro near to Sulmona and on the Bradana in proximity to Foggia, as well as the masonry gravity dams which are provided for in the high valley of the Scrivia (Genoa), the one which should raise by 25 m. (82 ft) the level of the reserve of Lake Arno, and the Adamello and Lake Barbellino groups in the province of Brescia. As a reminder only we shall refer to the very important group of dams provided for on the different tributaries of the Neto in Calabria, on the Fortore near to Foggia, where the dam will have a height of 75 m. (246 ft), on the Coghinas in Sardinia, the Simeto in Sicily, the Enza in the province of Parma, as also the curved dikes of the Corfino in Tuscany, of Muro Lucano in Basilicate, and of the Maina in Venice, which will have a height of 70 m. (230 ft) and will be the most important of the curved dams built in Italy.

We shall limit ourselves to describing the earthen dam of the Lagastrello, the three rubble dams of the Alpone, the Biascinna and the Devro, and the masonry gravity dams of the Badana and the Brasimone.

Our colleague, Mr. Forti, in the second part of this memorandum, will deal with curvilineal dams as also with reinforced concrete dams.

II. — THE LAGASTRELLO EARTHENDAM

This work (fig. 1, plate 1) is the first example of a high earthen dam built in Italy; it is established in the valley of the Enza, 1,160 meters (3,800 ft) above sea-level and about 60 miles from Parma.

The hydrographical basin that feeds the reservoir closed by the dam is 4.33 km² (1.55 sq. miles); to this basin must be added a derivation canal the extent of which is 0.52 sq. miles so that the lake is formed by the rain water of a zone having a little more than 2 sq. miles of surface. The capacity of the Lake is 3,000,000 m³ (3.9 million cub yds). The mass of the dam is 143,000 cub yds and the length at the top 170 m. (185 yds). Its thickness at the base varies between 81 and 90 m. (265 and 295 ft), and its greatest retaining height, measured from the bottom of the lake, is 21 m. (69 ft). The foundations, in certain parts, go down to 5 m. (16.4 ft) below the bottom of the valley.

The lake serves principally for feeding the Rimagna hydro-electric Central Station, which utilises a fall of 160 m. (525 ft) and that of Isola de Palanzano which benefits from one of 355 m. (1,165 ft). In the canal feeding these Central Stations also flows the water from the reservoirs of the Cedra torrent, the reserve of which is formed by masonry dams 12 to 18 m. (39 to 59 feet) high. These reservoirs form real lakes with a total capacity of 3,700,000 m³ (4,840,000 cub yds). The force produced in the Central Stations is nearly 10,000 HP. and is supplied to the towns of Spezia, Carrare, Massa, and some part also to Parma. The water after coming out of the turbines is used for irrigation purposes.

The increase of outflow produced by the two systems of reservoirs may be estimated at, on an average, 1000 liters (220 gals) per second during the most critical period for irrigation, and this raises the low-water mark of the Enza by a corresponding quantity to the great benefit of agriculture.

By reason of local conditions, which are but little favourable to the construction of masonry dams, but very favourable to the building of earthen dams, the bottom of the old lake being composed of an abundance of clayey matters of the best quality, the section represented in fig. 1 was adopted for the dam.

It is a *combination of the English type*, with a partition of pure well-beaten clay, — a kind of *puddle* (1) of the English — and *the French type*, which has for its characteristic feature the strengthening wall at the foot of the slope. This slope is protected against the erosive action of the waves, which are very violent in these regions exposed to strong winds from the sea, by means of a covering, one meter (3.28 ft) thick, composed of rubble covered with dry masonry of rough-hewn blocks of sandstone 1 foot at the ends. Sufficient flexibility has thus been given to this covering for it to follow without sensible deformation the slow subsiding due to the pressure of the clayey mass, whilst the water-tightness is naturally secured by the earth of the mass and especially by the purity of the clay of which the central partition is formed.

In order that the inner slope may not have a tendency to fall in when it is impregnated with water, after a long rainy season, it has been made to rest against a large staying wall composed of broken-stone. This wall, at the same time allows of suitable drainage.

During the construction, when the crest of the dam had not even reached the height of the spill-way, an exceptional and unexpected flood arrived after a fall of 22 inches of rain (from the 18th to the 21st December 1909) this was aggravated by the melting of the snow caused by a warm south wind, and the lake was suddenly filled, in spite of the discharge by the bottom outlet, which allowed of a discharge of 10.4 cub yds per second. The water went over the top of the work, and, when flowing over, produced a deep erosion of the dam which extented to its base, and the lake emptied itself completely. But thanks to the perfect density of the clayey mass of the dam, and especially thanks to the central partition of *puddle*, the erosion proceeded so slowly and by such a narrow crack that 7 hours were neces-

(1) The puddle is a mixture of clay, sand and gravel, that is to say a kind of concrete in which the lime or the cement is replaced by clay. The composition of the mixture is one part of gravel, 0.35 of coarse sand, 0.15 of fine sand and 0.20 of plastic clay. The whole is moistened with a little water and carefully worked, the result being a plastic and very impermeable mixture.

sary for the total discharge of the water, so that no notable damage was caused in the valley.

The following year, in the spring, the work of repairing was commenced and in 1913 the water rose to the height of the spill-way; this latter has a length of 17 m. (18.58 yds), and can allow a flow of 30 m^3 (39 cub. yds) per second, that is to say of 19 1/2 cub. yds per sq. mile of basin, with a depth of 3.28 ft for the overflow, and so as to leave a space of 11.5 ft, which guarantees that the water of the lake will never again flow over the top of the dam.

The dam at the present time works perfectly, without any loss of water, although the banks are of morainic formation and in consequence relatively permeable. By reason of the damage caused when the work was on the point of being terminated, four summers were necessary to build the dam. Its cost amounted to 620,000 francs, including the accessory installations for evacuating the bottom deposits, for the water-intake and for the surface spill-way.

The inner safety wall of 7,800 cub. yds and the dry rubble lower wall cost about 115,000 francs; the earth mass of the body of the dam came 104.55 francs per cub. meter (1,308 cub. yds), but if we take into account the volume of earth carried away by the flood of 1909 this price is assuredly moderate.

Normally the lake fills up four times a year, and this gives 12 million m^3 (15 1/2 million cub. yds) of water, of which each meter produces, at the two Central Stations, a force of 1 kilowatt per hour. Under these conditions, and in spite of the relatively high cost of the dam, the installation is most fruitful for the Company, which was able to distribute a dividend of 10 % in 1910; the resulting increase for the derived irrigation canals of the Cedra must also be taken into consideration.

The plan of this installation was drawn up by Professor Louis Zunini, Engineer of Milan, who, himself, directed the work with the cooperation of Messrs Ganassini and Inglese, engineers.

It is the first large earth dam built in Italy and could not have succeeded better.

III. — RUBBLE DAMS ON THE CENISCHIA, THE BIASCHINA AND THE DEVERO

Dams formed of a mass of broken stone, more or less hand placed, and afterwards made water-tight by means of a central partition according to the process employed for the old dams, or by means of a partition placed on the higher slope, as is generally done to-day, are fairly well known, especially in North America, where we find them from 30 to 40 meters high and even 51 meters (167 ft) (the Morena dam in California). They are still rare in Europe, and it is only now that our continent has begun to adopt them in practice.

a) *The Lake Alpone Dam*

For the first attempt of this kind in Italy we must go back to the year 1906, when the construction of a dry rubble dam was undertaken at the outlet of Lake Alpone, in the valley of the Cenischia which flows down from Mont Cenis.

The attempt was modest, even timid one might say, because of the novelty of this kind of work in Italy, which, it is generally supposed, ought to be constructed of solid masonry, as was done by the Romans.

The dam is situated more than 2,000 meters (6,560 ft) above sea-level (fig. 2); it is composed of a mass of dry stones 7 meters (23 ft) high, 7 meters (7.65 yds) wide at the base and 3 meters (3.28 yds) at the crest. The masonry foundation, made of cement mortar, is from 1 1/2 to 3 meters (4.9 to 9.8 ft) in thickness with a width of 8.50 meters (9.3 yds), solidly embedded in the rock.

Great care was given to the execution of the stone mass, which was made water-tight by means of a layer of concrete applied to the upper face, and this formed the partition. This upper face has an inclination of 3 for the base to 5 in height and the resultant of the water pressure passes through a point of the foundation floor which almost coincides with the center of the base through which the line of action of the weight of the dam passes. The result, per unit of surface, is a sufficiently reduced pressure on the foundations.

The work is water-tight and a complete success, which does honour to its engineer, Mr. Barbieri, who was the first to adopt this type of dam in Italy. The volume of water in the reservoir created by this dam is about 150,000 m³ (196,000 cub. yds).

b) *The Dam on the Biaschina*

This work, established on a confluent of the Tessin, serves to increase the volume of water of the small Lake Chironico situated 5,884 ft above sea-level, and 3 kilometers (1 7/8 miles) from Giornico station.

The greatest retaining height of the dam is 11 meters (36.1 ft) : it is therefore also a relatively modest work.

It includes (fig. 3 and 3 bis) a masonry mass of dry stones, the upper slope being 1 : 3 and the lower one 1 : 2.

Against the upper side a cement masonry partition has been applied, which in its turn *is covered with reinforced concrete with sheets of metal in order to form an impermeable screen.*

This work was executed in 1912 and has given complete satisfaction.

c) *The Dam on the Devero*

This dam, established on a tributary of the Toceet, which is now being finished, is situated at an altitude of 1,866 meters (6,121 ft) above the level of the sea at about 30 kilometers (18 3/4 miles) from Domodossola. It is destined to utilise the waters of a hydrographic basin of an area of 26 km² (about 10 sq. miles) and to form a reservoir of 13,000,000 m³ (17 millions cub. yds) to supply the two electric stations of Goglio and St Martino of 40,000 HP.

Here it is a question of an important enterprise (fig. 4 and 4 bis) of which the culminating point is 31 meters (101.7 ft) above the lowest point of the foundations. It includes a large mass of rubble 115 meters (122 yds) long at the summit, the higher slope being 1 in 1 and the lower 1 1/4 in 1. The useful retaining height is however only 21.80 meters (74.5 ft) and the crest of the dam rises 2 meters (6 1/2 ft) upwards from the maximum level of the reservoir.

The foundations rest partly on rocks and partly on moraine, mixed with slime and erratic boulders, which would constitute a

very bad soil for earthen or masonry dams. For the rubble dam this soil presented no inconvenience, thanks to the possibility of subsidence without noticeable deformation, which is a very important advantage in favour of this kind of work.

For the higher half of the dam the mass of stones was arranged hastily by hand without, from this fact, constituting regular dry masonry; for the lower half, on the contrary, the layers of stones placed pell-mell alternate with layers of regular dry masonry, with a view to better splitting up the interior stresses.

The watertightness of the work is secured by *a covering of cement mortar masonry*, applied to the inner slope and rendered still more impermeable by *a double layer of asphalte*, protected in its turn by *a double coating* of cement mortar and by *a covering of granite blocks*, 0.40 meter (1.3 ft) at the small end, laid with cement mortar, the asphalte is thus protected from sudden variations of temperature and from floating bodies which might damage it.

This is a pretty bold piece of work, for an European, but it was well thought out in all its details, and is worthy to be compared with the rock-fill dams which are numerous enough in the United-States. Among these dams we may mention, as examples, the one on the Stanislaus River, 42.60 meters (139.7 ft) high and that on the Morena River, 61 meters (200 ft) high, these being the two most typical kinds.

The Devero dam was planned by Mr. Joseph Villoresi, engineer of Milan, who also directed the work. The building of it took two summer seasons, work having to be carried on at nearly 2,000 meters (6,560 ft) above sea level and only being possible during a few months of the year.

It cost 868,000 francs, thus 0.0698 fr. per cub. meter (1,308 cub. yds) of reservoir volume and 16.07 frs per cub. meter of dam volume, the usual accessories being included.

Notes concerning rubble dams.

The three works, of which we have just given the outlines, constitute types of dams which are more or less novel for us, Europeans; they are however quite rational, and, as we have already said, well known in the United States.

The rubble mass which forms the body of the dam costs little and is easy to set up, even during the periods of frost, a fact that has its value when work has to be carried on at a great altitude above sea-level, i. e. when the working months are necessarily limited. The stone mass offers the desired resistance to the pressure of the water, and thanks to the extensiveness of the base, this pressure gives rise to stresses on the foundations which, per unit, are very reduced. It is not even necessary that the foundation soil be composed of compact rocks, which, on the other hand, is indispensable for ordinary and masonry dams.

For the foundations a schistous or marly sub-soil can be tolerated, or even one of glacial origin, provided that it be impermeable. This is a very important point for dams to be constructed in Southern Italy, in Sardinia and in Sicily, and eventually in Eritrea and in Lybia, where the foundation soils are generally of very poor quality and little suitable for constructing masonry dams, while these same soils allow of rubble dams.

What is more the building up of the dry masonry which forms the body of the dike is very easy, even with local labour, and the cost is moderate; another thing is that it is not liable to subsidence or to any perceptible movement in the interior of the dam. A heavy mass is formed, which, while being rigid enough to resist the push of the water, is also able to support the slight subsidences of the foundation soil without any appreciable deformation.

In order to render the rubble masses impermeable it is enough if an asphalte or reinforced concrete partition is made, as we have said, on the inner slope, this being covered with a layer of masonry or hydraulic mortar, which is not likely to crack and in which, at the most, slight cracks, easily repaired, may appear.

And again, if cracks were to appear in the partition when the dam is under load, there would be no resulting danger, either from the point of view of sub-pressures, which are greatly to be feared with masonry dams, of from the point of view of the softening of the material or of slipping, things which happen very easily in the case of earth dams. On the contrary when the body of the dam is composed of large stones or of dry

masonry, the percolating water easily finds an outlet through the spaces that exist between the stones, and the only resulting damage is a fairly slow loss of water. In no case can the dam suddenly break, and there is no imminent danger either to persons or to property, this being one of the chief anxieties of engineers who are obliged to erect large dams for reservoirs.

Even the danger of an instantaneous rupture caused by an earthquake, that is to say the only danger that still threatens large masonry dams, even those built with the aid of the most ingenious artifices and with all possible precautions, is eliminated in this new type of dam, for the mass of the dam, with its extensive base, may subside or lose its shape but it can never collapse: the partition on the higher slope may split and let the water of the reservoir escape, but this water, which must pass through the cracks and then by the spaces between the stones, can only flow with a certain slowness and never all of a sudden as could happen in the case of a masonry dam.

One of those terrible floods, which have caused so many disasters, can therefore never happen. From this point of view, the placing of the largest blocks at the foot of the lower slope is to be recommended, these should be well arranged so as to give a solid support to the rubble mass and prevent it from giving way even if large volumes of water should escape through the dam owing to the rupture of the partition which covers the inner slope.

The only other precaution that one could take, in countries subject to earthquakes, would be to give to the inner slope an inclination of at least 1 1/2 to 1 3/4 base to 1 in height, which corresponds to the slope of the volcano Stromboli, which has almost daily irruptions and undergoes violent shocks. The dam would then be invulnerable and would resist even eartquakes. With such a slightly inclined slope, the work would also have but little to suffer from the flowing of water over its crest in times of tempest, as was demonstrated by the provisional rubble dams established on the Nile (1) on the occasion of the building of the

(1) L. Luiggi. « La Diga di Assuan sul Nilo ». Annali Società Ingenueri e Architetti Italiani. Roma 1913.

great Assouan dam. At certain points the height of these provisional dams reached 15 meters (49 ft) and yet a good part of the Nile water passed over; thanks to the slight gradient (about 1 1/2 : 1) of their slopes these works however resisted perfectly, and in order to demolish them, after the completion of the work, dynamite had to be used.

Rubble dams are therefore types which are worth knowing, which provide an easy and economical and above all certain solution even in those countries where seismic shocks are frequent.

Their adoption is therefore to be recommended for Calabria, Sicily, Eritria and also for certain valleys of the Argentine Andes which are also exposed to earthquakes.

IV. — MASONRY DAMS ON THE BADANA AND THE ERASIMONE

a) *The Badana dam*

This work forms part of the group of the five large reservoir-dams of the Gorzente, of which three are destined to supply Genoa and, in a subsidiary manner, to supply electrical energy, and the two others to regulate the swellings of the waters of the Gorzente and to increase the low water. One of these two last dams is under construction at 720 meters (2,362 ft) above sea-level, in order to form a lake with a capacity of 4,664,500 m^3 (about 6,100,000 cub. yds) fed by a hydrographic basin of 4.8 km^2 (1.85 sq. miles) where the rainfall is so abundant — the greatest in Italy — that each year the fall measures from 2 to 2 1/2 meters (78 3/4 to 98 1/2 inches).

During an exceptional storm an overflow of 12.9 m^3 (15.7 cub. yds) per second and per sq. kilometer of hydrographic surface will be measured at the spill-way of one of the three other dams, this hydrographic basin has a surface of 9 sq. kilometers (nearly 3 1/2 sq. miles) and, being deprived of any kind of vegetation, the floods are sudden and very dangerous.

The length of the dam at the top is 215 m. (235.4 yds), its

ordinary retaining height 48.90 m. (160 ft) and that corresponding to the highest level of the lake 1.50 m. (4.9 ft) more.

The total height of the work above its foundations is 56 m. (183.7 ft); it is therefore the highest dam in Italy.

The foundation soil is composed of very compact serpentine-stone. The total volume of the masonry work is approximately 100,000 m^3 (130,800 cub. yds).

The plan of the dam is slightly curved, but it is calculated as if only resisting by its own weight. The section (fig. 5) which results still shows the shape of the old Gorzente dams, which one might already qualify as antiquated, but one is obliged to admit, that these works were a decided success. The higher profile of the wall presents a variable batter of from 5 to 30 %. This inclination is perhaps a little too strong in comparison with the modern profile of the inner face of dams, which is generally vertical or of which the batter does not exceed 10 %. The lower profile, which has inclines going to 100 %, does not agree with the ideas recommended by Mr. Lévy, and which are actually adopted by builders. The Brasimone dam, which we shall describe further-on, on the contrary satisfies these new ideas; this was their first application in Italy, and the Fortore dam, 75 m. (246 ft) high, which must be constructed in the near future, will be a second and still more important application.

In the theoretical profile of the Badana dam (fig. 6) there is not, in the masonry joints on the inner face, when the reservoir is full, a vertical pressure superior to the corresponding hydrostatical pressure, as is recommended in order to counterbalance eventual sub-pressures. Then the lower part of the outer profile of the wall, of which the batter is 1 : 1, i. e. 45°, is too steep; Mr. Guillemain and after him Mr. Lévy considered that this angle ought to be the smallest possible, in order that the *maxima maximorum* pressure and the peremptory stresses should also be as small as possible.

But, even making abstraction of these theoretical considerations, and athough the vertical or normal pressure at the joints may be 6.09 kg. (13.4 lbs) per cm^2 (0.154 sq. ins), according to the law of the trapezium or of Méry, and reaches 12.18 kg. (26.8 lbs) per cm^2 according to the Method of Mr. Lévy, the Badana

dam stands in the same conditions as the other dams of the Gorzente, which have given excellent results. Thus the Laveze dam, 37 m. (121.4 ft) high, is submitted to vertical pressures of 7.35 kg. or 11.51 kg. according as one applies the aforesaid law or the method of Mr. Lévy. For the Lagolungo dam, 45 m. (147.6 ft) high, these are 5.17 kg. or 10.34 kg., and for the Lavagnina dike, 17 m. (55.8 ft) high, 9.40 kg. or 14 kg. per square centimeter (0.154 sq. inches).

As we have just said, these dams have given excellent results and the Badana one will doubtless do so also; especially if we take into consideration the good quality of the mortar employed and to the great care taken in the execution of the stone-work, formed of large blocks of serpentine-stone and of mortar composed of one part of ordinary lime, one part of Roman pouzzolane and one part of sand. On an average thickness of 0.50 m. (1.64 ft), both on the inner and outer slopes, this mortar has been replaced by a slow-setting cement mortar, and these parts of the masonry were executed at the same time as the part of the interior mass. The dam was calculated on the supposition that the masonry weighs 2.3 tons to the m^3 (1.308 cub. yds) and that the maxima maximorum pressure, according to Mr. Lévy's theory, is always inferior to the safety load limit, which has been taken here as if it were a question of masonry of excellent quality, equal to 15 kg. per cm^2 (33 lbs per 0.154 sq. inches).

By reason of the hard frosts which occur in the Gorzente region, about 10 months of work were required for the building of the dam, divided into six summer periods, from 1908 to 1913. This long duration was also due to the difficulty of finding good masons inclined to work at such a high altitude in a region distant from any centre of habitation. In order to attract them and to persuade them to remain, it was necessary to provide them with dwellings and to supply them with special commodities, to supply them, use was made of the aerial cable railway 4 1/2 km. (2.8 miles) long, which was intended to transport the necessary materials for making the different kinds of mortar.

2,323,764 francs were spent on the dam thus 22.23 frs. per m^3 of stone-work and 0.49 fr. per m^3 of reservoir.

The plan was drawn up by the engineers, On. Reggio and

Finocchietti, and the work carried out under the direction of the engineers Finocchietti and Oliva. The results obtained have given entire satisfaction to the Aquéduc de Ferrari-Galliera C°, who also erected the other dams on the Gorzente.

Syphon exhausters for drawing off flood water.

One of the particularities of the Badana dam resides in the adoption, for drawing off the swelling of the waters, of syphon exhausters of the *Gregotti* type (figs 6 and 7) instead of the ordinary surface spill-way.

This automatic syphon system had already been adopted for the Lagolungo dam and even earlier, in 1906, for the Cenischia one (fig. 8).

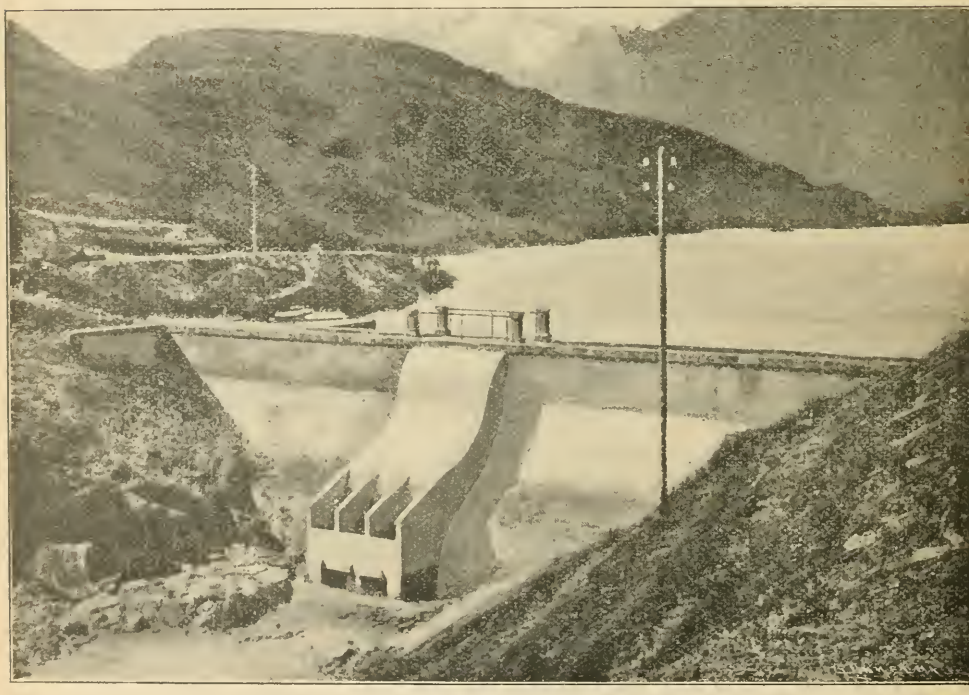

Fig. 8. The Cenischia automatic syphon weir.

By reason of the small width of the gorges blocked by these two constructions and of the exceptional rainfall that occurs in their hydrographic basin, where, as we have said, falls of 12.9

m^3 per second per sq. kilometer are registered, the building of ordinary weirs would have required a very large development and a great expense. It would, besides, have been necessary to allow a considerable depth for the overflow and consequently loss of water, the weirs provided with automatic syphons, on the contrary, allow of retaining in the lake a large part of this water to be utilised later on.

At the weir of the Lagolungo dam, where one day a depth of 1.40 m. (4.6 ft) was measured for the overflow, this depth was reduced to 0.10 m. (4 inches) only after the establishment of a system of ten syphons of 15 m^3 (19.5 cub. yds) output each. The maximum level of the rising of the lake was at the same time lowered by 0.30 m. (0.98 ft); as a result there was, on the one hand, a surplus of 1 m. (3.28 ft) of retaining height for the lake water, which increased its capacity by nearly 300,000 m^3 (392,000 cub. yds) and constituted a remarkable benefit for the town of Genoa, where, because of the growth of the population, it is necessary to consider the matter of increasing the water reserve.

Six syphon exhausters, with a total output of 80 m^3 (104 sq. yds), were placed at the Badana dam.

The syphons are of the Gregotti type (figs 6 and 7) which are very well known in Italy, where already more than 70 are to be found. The most important installations, after those of the Gorzente, are at the St. Giovanni Lupatoto hydroelectric Central Station, near to Verona, with an output of 100 m^3 (130 sq. yds) per second and a fall of 6 m. (19.7 ft), at the Robbiate Central Station on the Adda with an output of 80 m^3 (104 cub. yds), at the Santhia experimental hydraulic Station, output 30 m^3 (39 sq. yds), there are still others which have always given excellent results. The fear that these syphons might not always work regularly in winter, because of the hard frosts, has been set asisde thanks to the precaution which has been taken of making an orifice of 20 to 30 cm^2 section at the bottom of the small cup of the syphon. In this way as soon as the syphon ceases to act, the water contained in this cup begins to run off slowly and has not time enough to freeze. As soon as the syphon recommences to act, the water which runs down from the higher arm again fills the cup, the hydraulic closing of the syphon is reestablished, and

the apparatus works automatically; it is then once more in the desired condition for regular work. Thanks to the adoption of concrete for the construction of these syphons, which is preferable to iron or cast-iron, for the need of transporting large and heavy pieces up high in the mountains is thus avoided, it is possible, on the other hand, to give a considerable thickness to the sides of the syphon and this hinders the formation of ice in the interior of the apparatus.

The two sets of syphons of the Gorzente have always given excellent results, although they are installed at over 700 m. (2,297 ft) above sea-level, and in a valley exposed to the North, that is to say in a region where the frosts are pretty severe and of long duration. A fortiori their use is to be recommended in positions where the climatic conditions are less rigorous. In this way a better utilisation of the capacity of the lake is arrived at seeing that a volume of water corresponding to the depth of the overflow of ordinary dams, which would otherwise be lost uselessly, may be turned to advantage.

b) *The Brasimone Dam*

This work recently constructed on a tributary of the Serra, which flows into the Reno in the high Bolonian Apennines, is desined to form an artificial lake with a capacity of 5.600.000 m³ (7.324.000 cub. yds) fed by a hydrographic basin of 14 1/2 km² (5.6 sq. miles).

The water of this reservoir is utilised at the Casiglione dei Pepoli Central Station of 1,600 HP, from where the current is transmitted to Bologna, a distance of 60 km. (37 1/2 miles).

The height of the dam (figs 9 and 10) is 34.50 m. (111.5 ft) of which 1 m. (3.28 ft) for the foundations, which stand on sandstone rocks of good quality, and 32 m. (105 ft) for the actual water reserve; when the lake is full the sheet of water passing over the weir has a depth of 1 m.

The maximum level of the lake is 829 m. (2,718 ft) above sea-level.

The crowning of the dam is placed 1.50 m. (4.92 ft) above the maximum level of the lake.

The work has a total length of 158 m. (172.8 yds) at the crest.

and the plan is strongly curved, being traced with a radius of 74.50 m. (81.42 yds) and an angle of 128° 32' at the centre. It is solidly built into the rocky slopes of the valley at each end.

The section of the wall was calculated as though it had to resist the pressure of the water by its own weight, and the excess of stability resulting from its curvilineal disposition, gives an increased guarantee and also served to tranquillise the population of the valley of the Brasimone, who protested against the creation of the lake through fear of floods.

At its base the dam has a thickness of 23.03 m. (25.18 yds), of which 0.70 m. (2.3 ft) corresponding to a batter of 0.22 : 1 of upper facing, and the rest represents the inclination of 2 : 3, that is to say of 0.66 : 1 of lower wall facing. The thickness at the top is 4 m. (4.37 yds) for the solid part of the wall and 2 m. (2.19 yds) for the part with arches, thus altogether 6 m. (6.56 yds), which allowed of the construction of a road, supported by a series of arches and pillars, which increased the beauty of the work. The total volume of the stone-work is 40.000 m³ (52,000 cub. yds).

The method of calculation adopted by the engineer Mr. Omodeo, who is the designer of this dam, and who has built or planned others, is exposed in a note due to his collaborator Mr. Mangiagalli (1).

In order to determine the conditions of stability of the work, the recommendations of Mr. Lévy were followed, that is to say the wall was calculated in such a way as to place in equilibrium by its weight the hydraulic pressure and to be able to resist eventual sub-pressures without exceeding certain limits of compression in the stone-work.

Under these conditions, the profile chosen which, with a maximum of economy presents also a maximum of stability, constitutes at the present moment, after all the hypotheses admitted formerly, and after all the more or less successful applications, as well as after the serious misfortunes which have had to be registered, a so to say definite profile, thanks to the mathematical researches of Lévy in France (2), of

(1) « Le Barrage de Brasimone. » Il Politechnico Milano, 1913.

(2) Lévy. Comptes rendus de l'Académie des Sciences, 5 août et 4 juillet 1898.

Intze in Germany (1), of Unwin in England (2) and of several other authors, who have studied the problem from a theoretical point of view, since 1895, that is to say after the rupture of the Bouzey dam. The results of these researches were controlled and confirmed by the direct experiments of Atcherley, later renewed and completed by Brightmore Otley, Wilson, Gore and many others (3).

The profile adopted (fig. 8) is a triangular one presenting a very small inner batter (2.5 %), which has for its object the directing of the masonry into the joints, when the dam is under load, at a pressure a little superior to the corresponding hydrostatic pressure and which at the same time is sufficient, that, when empty, the pressure may not exceed the safe load of the masonry, on the inner side, and that no stresses may develop in it on the outer side. The outer facing is traced conformably to a batter of 0.66 : 1 resulting from the proportion :

$$\text{Base} = \text{Height of water} \sqrt{\frac{\text{density of the water}}{\text{density of the masonry}}}$$

In the case under consideration the unit weight of the masonry composed of large blocks of stone bound together with Portland cement was taken as 2.3 tons per m³ (1.308 cub. yds), which gives :

$$B = H \sqrt{\frac{1}{2.3}} = 0.66\ H.$$

The summit of the angle made by the outer facing with that of the inner coincides with the highest level of the lake. The surplus given to the upper masonry in order to raise the crest by 1.50 m. (4.9 ft) and to widen it to 4 m. (4.37 yds) in order to form a roadway, contributes to the increase of the stability of the work; this stability is still further increased by the curved form of the dam, so that it could even work as an arched dam. The work is there-

(1) Intze. Bau der Tahlrperren Acquisgrane, 1906. Ziegler-Tahlsperrenbau. Berlin, 1911.

(2) Unwin. Stresses in masonry dams. London Institute of Civil Engineers. 1905.

(3) L. Luiggi. L'evoluzione delle dighe per laghi artificiali. Italian Society of Sciences, 1913.

fore capable of resisting sub-pressures and exempt from all cause of danger. For this reason it was useless to provide either *a safety wall*, according to the methods of French builders, or *interior drains* with inspecting galleries as is done more especially by the Germans and the Americans. It was also possible to dispense with any waterproof coating on the inner face, for, as the designer of the dam says « this efficacious and rational » defensive measure against possible infiltrations and the sub- » pressures which are the consequence of them and constitute » the greatest danger for dams, — as has been so often esta- » blished — could not be adopted in the present case, firstly » because of the moderate retaining height of the work, which » is 32 m. (105 ft), also because of the perfect execution of the » masonry work and the solidity of the rock foundations, and » again because of the arc form given to the dam, which was » possible thanks to the narrowness of the valley which had to » be blocked. This form allows us to suppose that the dam works » at least partially as an arched dam, and in this case the infil- » trations do not present any danger and are reduced uniquely » to inappreciable losses of water.

» The maximum vertical pressure on the outer joints with a » load of 32 m. of water is 6.675 kgs. (14.65 lbs) per cm^2 (0.155 » sq. ins). The maxima maximorum pressure resulting from » Mr. Lévy's theory would be 9.63 kgs (21.19 lbs) per cm^2 which » is still quite admissible, especially in the actual case, the » masonry-work having been executed with cement-mortar which » offers a resistance to compression of 200 to 350 kgs (484 to » 770 lbs) per cm^2. It is not possible for any stress to developp » here in the dam and the relation between the vertical pressure » in the stone work under load and the corresponding counter- » pressure of the water does not go below 0.360. »

The maximum pressure, when the reservoir is empty, is found along the inner base arris and never exceeds 7.27 kgs (16.98 lbs) per cm^2.

The stability against slipping is amply provided for throughout the height of the dam, and the shearing efforts are also maintained within the limits of desired safety.

A very important accessory for dams, and which Mr. Lévy

calls their safety-valve, consists in the spill-way, which has been given here a length of 80 m. (87.4 yds) to drain off, with a depth of 1 m. for the overflow, a swelling of 110 m^3 (143 cub. yds) to the 1", calculated for a rainfall at the rate of 7.5 m^3 (9.75 cub. yds) per km^2 (0.38 sq. miles) of hydrographic basin per second, which nearly agrees with what has been ascertained for the Lagastrello reservoir which is in similar pluvial conditions.

The stone-work of the dam consists of large blocks of sandstone of very good quality with Portland cement and artificial sand, made by crushing and granulating the sandstone. The quantity of mortar varies in the different parts of the work, and contains from 300 to 500 kgs (660 to 1100 lbs) per m^3 (1.3 cub. yds) of sand. Throughout the length of the base of the dam and to a height of 2 m. (6.56 ft) above the plan of the foundations as also for a thickness of about 1.50 m. (4.9 ft) of the inner facing, rich mortar was employed, that is to say mortar containing 500 kg. of cement per m^3 of sand, after 28 days capable of a resistance of 23 kgs (50 lbs) per cm^2 to traction and 285 kgs (627 lbs) to compression.

For the rest of the wall, *the quantity of cement was reduced progressively as the work receded from the inner face and rose above the foundations*, until the minimum of 300 kgs per m^3 of sand for the dam itself and 250 kgs for the crowning situated above the level of the water. Even with this latter quantity the mortar still offers a resistance of more than 150 kgs (330 lbs) per cm^2 to compression.

By thus varying the composition of the mortar, a greater impermeability of the inner facing and of the foundations is realised and this as far as possible prevents infiltrations; if however infiltrations should occur, then thanks to *the decreasing degree of impermeability of the masonry going from the higher to the lower faces*, the water can easily escape by the lower facing without exercising any sub-pressures in the mass of the dam. In other words a properly called drainage has not been provided on the inner face as is actually done for very large dams, but resource has been had to a contrivance much employed by the best English builders, and of which the Tytam dam at Hong-Kong offers a standard example: this contrivance prevents eventual infil-

trations from exercising perceptible sub-pressures or other stresses in the mass of the work. Special care was also taken, in the upper part of the dam, in the placing of the large blocks of compact stone, and on the face seen a facing of rough stone was placed with rich mortar, with cement in the proportion of 1 : 1, suitably rejointed.

As the designer of the dam has pointed out « when one disposes » of stone of good quality, absolutely waterproof, it is useless to » cover the inner facing with a coating, which besides always » presents some difficulties if one desires a perfect execution, » and also by reason of the necessity of using special mortars, » as these latter should permit of the rapid placing of the coating » and at the same time of perfect adhesion to the masonry, » without the danger of cracking from the effect of the differ- » ences of temperature or from humidity, they should also be » able to resist the small and almost incessant shocks and vibra- » tions of the earth's crust. »

The difficulty of obtaining a good coating increases considerably when large surfaces exposed to the sun have to be covered.

The rejointing also calls for, it is true, perfect execution, and it must be confided to very conscientious workmen, but it is easier to carry out and more certain. It however presents this inconvenience than when a crack is produced by the inevitable contractions and dilations of the masonry under the action of the temperature, it is more difficult to discover and may pass unperceived during a long time.

It is for this reason that drains and inspection galleries, which allow of noticing these accidental infiltrations, have their usefulness and are employed in large modern dams.

For the Brasimone dam, taking into account its relatively moderate height and its curved shape, which increase considerably its conditions of stability and make it almost safe from sub-pressures, the system of protection by a facing of squared stone with carefully rejointed joints was judged sufficient and has given very good results; which are also due to the perfect execution of the masonry-work and of the foundations; in this manner all subsidence has been avoided, and neither cracks nor appreciable infiltrations are discernible on the outer face of the dam.

The sweating also has a tendency to disappear.

One may say that it is really a perfect piece of work and one which does honour to its designer.

With its accessories the dam cost 800,000 francs, thus 20 frs per m^3 of masonry-work and 0.14 fr. per m^3 of reservoir capacity; these are very modest figures resulting notably from the abundance of labour and from the excellent quality of the materials that are found on the spot. It was only necessary to have the slow setting Portland cement sent, and cement was adopted instead of lime or pouzzolane, which are usually used in Italy, precisely to diminish the cost of transport. It was also for this motive that, at Tripoli, the writer preferred to use, for the construction of a mole — a thing done for the first time in an Italian port — artificial blocks composed of cement, sand and rubble, instead of lime, of pouzzolane and rubble, as is usually done.

Observations on the masonry dams constructed in Italy.

Not one of the existing masonry dams in Italy, ancient or recent, described in what precedes, was provided with drains in the foundations or on the side of the inner facing, nor had they inspection galleries or shafts. The masonry-work is also without any expansion joints, whilst joints of this kind have been provided for in all the most recent large dams constructed in Germany, in England and especially in America where the most remarkable examples are to be found, among which the superb Arrow Rock dam, 106 m. (347.7 ft) high, which will soon be finished and will be the standard model of this kind of work.

The absence of these precautions and means of control is justified by reason of the moderate height of the Italian dams built till now, a height which does not exceed 60 m. (196.8 ft) for any one of them, and because of the relatively slow setting hydraulic mortar employed, as are the different kinds of mortar, lime and pouzzolane or hydraulic lime and sand, which are generally used. It is only recently that Portland cement has begun to be used. Pouzzolane mortar develops but little heat at the time of setting and remains plastic for a long time, and, because of this, masonry-work executed with this mortar is not subject to cracking by reason of the contractions and dilations, while

this cracking is characteristic of the masonry-works made of Portland cement mortar. The writer had the opportunity of studying this question, when examining the most characteristic example of cracks of this kind produced in the Portland cement masonry-work of the magnificent Assouan dam on the Nile. This truly monumental work (1) which has a length of nearly 2 km. (1 1/4 miles) in a straight line, presents, in spite of the great care given to its construction, 69 cracks of 1 to 2 mm. (1/25 to 2/25 ins.), due to the thermic contraction of the masonry, executed in the torrid climate of upper Egypt, where the stones were so hot that the workmen handled them with difficulty, and which caused phenomena that were much more evident than in other dams, such as those on the Mouche in France, on the Remscheid in Germany, on the Barosse in Australia and in still others, notably in the Cross-River, Olive Bridge and Kensico dams which are so well known on this account, in America (2). With lime and pouzzolane mortars, which are more plastic than the cement ones, on the contrary, the masonry-work may settle slightly during the process of setting, which is slow and requires almost a month, and they are thus so to speak free from cracks: this is also due to the fact that the Italian dams dam valleys which are open towards the north, so that the sun does not shine directly on either face, and the masonry-work being washed by the water of the lake during the greater part of the year feels but little the variations of temperature. It is thus that *the phenomenon of thermic contraction and dilation of masonry-work, which is so striking at Assouan is almost imperceptible in pouzzolane masonry dams.*

Besides, as these dams are generally strongly curved, the water-pressure on the back of the work tends to tighten up the different parts and this helps to close the cracks, should any be formed, and these cracks only produce almost imperceptible sweating which is quite harmless.

(1) L. Luiggi. « The Nile dams ». Annals of the Italian Society of Engineers, Rome, 1913.

(2) Merryman. « Cross River dam ». Proceedings of the American Society of Civil Engineers 1907, and « The Kensico Dam ». Report on the Catskill Aquaduct of New-York, 1913.

V. — INFERENCES

Taking into account the results given by the dams recently built in Italy, which we have described, and the results obtained from similar dams recently built elsewhere, the following inferences may be drawn :

1° Earthen dams are preferable to others and are more economical when clayey matter and labour are abundant and when the retaining height does not exceed 30 meters (98 ft) or there abouts.

2° Rubble dams (rock-fill dams in America) generally supply the most economical and the most certain solution; even in countries subject to earthquakes, for higher dams up to 45 meters (147 ft) in height.

3° Masonry dams are the most suitable for great heights, 100 meters (328 ft) and over, those with triangular sections and which resist by gravity, should be calculated in such a manner as to be able to resist sub-pressures also, in taking into account all Mr. Lévy's recommendations. It is also to be recommended that the plan be curvilineal and that they be supplied with draining contrivances, inspection galleries, dilation joints etc. calculated to preserve them in as good a condition as possible.

Masonry dams evidently do not supply the same resistance to earthquake shocks as do rubble ones, but this inconvenience can be provided for, in regions subject to such shocks, by embedding iron stays especially in the crowning, and by arranging in advance protecting platforms above and below.

4° One consideration, which should overrule all others when works of this kind are contemplated, is that one should have recourse to every precaution possible in order to prevent a sudden rupture of the dam and the quick outpouring of the water, even if these precautions lead to greater expense; assuredly it would be inadmissible in our days, for reasons of economy, to build dams that might cause disaters for the inhabitants of the valleys situated below these works. When all desired precautions are taken, these inhabitants will no longer oppose so vigorously the construction of reservoir-dams, the number of

which it will therefore be possible to increase to the great profit of the system of conserving rivers and the better utilisation of their waters, either for the production of electrical energy, or for irrigation-works or for the needs of navigation.

Prof. LUIGI LUIGGI.

Rome, May 1914.

SECOND PART (Pl. II)

ARCHED
AND REINFORCED CONCRETE DAMS

BY

Mr. Angelo FORTI

Engineer

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a) *Arched Dams.*

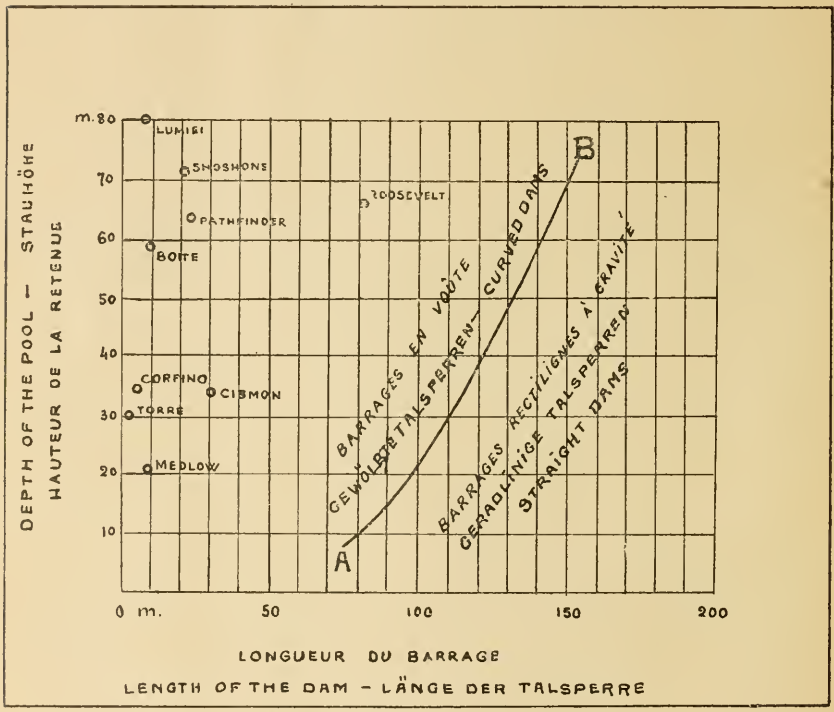
The arched dams viewed here are those of which the stability depends solely on their curvilineal shape and to the transmission of the hydraulic load on the lateral flanks of the blocked valley or on columns able to support the thrust.

Dams formed of a single arch supply, for determined widths of the valley to be blocked, and no matter what the height of the water-level may be, economical advantages the limit of which may be fixed comparatively with straight and solid dams.

In order to fix our ideas as to this limit, we have made out for different lengths and retaining heights, conditions of equality between the volume of the horizontal section of the base of the most favourable single-arched dam and that of the corresponding rectilineal gravity dam, and we have thus drawn the curve A—B of the diagram herewith.

This curve is the place of equal conditions, from an economical point of view, as defined above, which means that in admitting approximately that the volumes of the two complete works are proportional to their respective base sections, it may be inferred that the dams of which the characteristics, length and height, are found on the left of the line A—B, are advantageous for the single-arch type, while for the characteristics to the right of the line it is better to consider rectilineal and solid types of dams as also the multiple-arch type supported by intermediate columns.

Before beginning our examination of single-arch dams, to which this paper is specially devoted, it is useful to say a few words about multiple-arch dams, by drawing attention to the fact that the method of elastic deformations permits of calculating these constructions now in an absolutely perfect manner and that the works of this type, the oldest, Meer Alun, Belebula etc., like the most recent, Hume Lake and Big Bear Valley have given the very best results.



Setting apart the economical advantage, which must be examined for each separate case, the writer is therefore of the opinion that the multiple-arch type of dam merits full attention on the part of engineers.

Returning to single-arch dams, we notice that all the constructions on this system that exist in the world have the characteristics that distance them from the line A—B.

This verification thus confirms the opinion that single-arch dams should be adopted with real advantages even for great

retaining heights, when it is a question of stopping very narrow valleys with highly resisting rocky sides.

An innovation in the construction of arched dams, which will certainly find applications in cases where the width of the valley to be blocked varies greatly from the base to the summit of the work, consists in making the centre of the bend of the upper side vary suitably, taking it as a rule that the minimum of volume is obtained generally, even when taking elastic deformations into account, by an arc the opening of which is from 120° to 180°.

It is in taking the principle of the variation of the bend of the arc as a basis that the writer designed the Maina dam on the Lumici torrent, of which we shall speak later.

In our country, and especially in the Eastern Alps, there is often a need of forming reservoirs by means of very narrow dams, and one may say that our builders have accepted the principle that it is undoubtedly advantageous and rational for the construction of this kind to choose the single-arch type.

In support of what we have just said, we give the description of five Italian works of this kind, all forming part of hydro-electric plants. The three first are finished, the other two will be undertaken shortly.

Dam on the Torra Crosis Torrent (Undine).

(Figs 1, 2 and 3, Pl. II)

The Crosisdam, built in 1896, stops the very narrow gorge of the Torre torrent near Tarcento.

The total capacity of the reservoir was originally 800,000 m³ (1,020,000 cub. yds).

The work is 20 m. (22 yds) long at the top and only 2 m. (2.2 yds) at the primitive water level which is about 30 m. (98 ft) lower than the present. This would have been a typical case for adopting a single-arch dam; but while the upper part of the work was constructed, for a height of about 17 m. (55.8 ft), following an arc with a radius of 38.50 m. (32 ft), and with a superabundant section, for the lower 11 m. (36 ft), where the width of the gorge varies between 1.50 m. and 5 meters, the dam is rectilineal and one may say that is acts like an embedded girder.

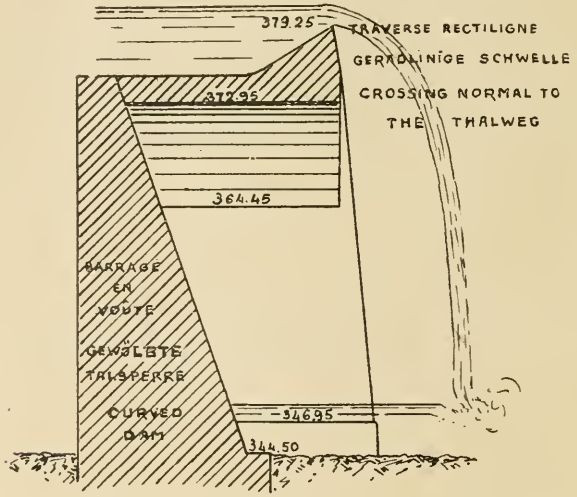
Later the work was raised another 2.5 m. (8.2 ft).

The Torre torrent has a hydrographic basin of 63 km² (25 1/3 sq. miles) and the floods pass over the crowning of the dam, which then acts as a spill-way.

Dam on the Cismon at Ponte della Serra.

(Figs 4, 5 and 6. Pl. II.)

The Cismon dam at Ponte Serra blocks a gorge which is submitted to erosion and hollowed out in cretaceous limestone; with a height of 34 m. (111 1/2 ft) above the primitive water-level it forms a reservoir of about 4,000,000 m³ (5,200,000 cub. yds) capacity. The hydrographic basin of the torrent has a surface of 395 km² (152 sq. miles).



Local conditions and especially the small width of the gorge, led to allowing an important part of the strongest floods, reckoned at 1000 m³ (1,300 cub. yds(per second, to flow over the crowning of the dam, and in order to avoid any possible damage from this fact the strange construction shewn in the sketch below was adopted. The dam, traced according to an unique archplan, has been provided with a fore-part with a higher rectilineal cross-piece over which the flood-water can fall freely in a parabola, far enough from the foundations of the arch, into the bed situated underneath.

The deepest overflow registered up to now over the cross-piece is 91 cm. (3 ft), and the discharge, took place without any noticable change in the conditions of the existing down-stream bed, although this latter is formed of shingle, of gravel and sand under a sheet of 5 meters (16 1/2 ft) of water.

The length of the dam varies between 30 m. (32.8 yds) at the base and 45 m. (49.2 yds) at the crowning, and the inner side, which is vertical, has a radius of 33 m. (36 yds) for the curve throughout its height.

This dam does not satisfy the principle of the maximum of economy, for the designer started with the idea that the thickness of the arch at the base must not be inferior to one-third of the height.

The fore-part consists of a viaduct formed by the arches of 17 m. (18 1/2 yds) opening and a central porch, the rectilineal cross-piece has a trapezoid section 4 m. (13.1 ft) high. The fore-part was calculated, from the point of view of stability, as being quite independant of the curved part. This dam was designed and built by the writer between 1907 and 1910 and cost about 900,000 lires (1).

Dam on the Corlino torrent.

This is a curved dam in the most extended sense of the word and which, by its audacity, recalls the types of dams known in New South Wales and especially the Medlow one.

The crowning of the dam forms an almost complete semi-circle and has a lenght of 63 meters (68.9 yds); the base has a width of 4 to 5 meters (13 to 16 1/2 ft).

The upper face or extrados of the arch has a uniform radius of 23.50 meters (25.7 yds) throughout its height. The maximum height of the hydraulic load is 34 meters (111 1/2 ft).

The rock in which the dam is embedded is of highly resisting green-stone. The reservoir formed by this dam is not very extensive, it has a capacity of 780,000 m^3 (1,015,000 cub. yds).

(1) Giornale del Genio Civile, Anno XLVIII, November 1910, Engineer Angelo Forti : Impianto Idro-Elettrico del Cismon a Ponte della Serra. Schweizerische Bauzeitung N° 25-26. Vol. LXI, 1913. Das Wasserkraftwerk am Cismon de Ponte della Serra.

The hydrographic basin of the torrent has a surface of 25 km² (9.6 sq. miles) and its greatest floods have been reckoned at 90 m³ (117 cub. yds) per second; they are discharged by means of a set of 5 Gregotti syphons with 8 outlets.

This dam was designed by Mr. Angelo Omodeo, Engineer of Milan.

Dam on the Boite torrent at Ponte Pocroce.

(Figs 7, 8 of 9 Pl. II)

This work designed by the Impianti Elettrici del Boite C°, of Venice, is destined to block, to a height of 60 meters (196.8 ft), a deep and very narrow gorge hollowed out in excellent limestone (dolomite).

The lenght of the dam is only about 10 m. (10.9 yds) at the base and 30 m. (32.8 yds) at the summit.

The wall in the form of an arc has a thickness of 13.50 m. (44.3 ft) for the foundations, and 4 m. (13.1 ft) at the crowning. The radius of the curve is 22 m. (24 yds) and the center is the same for the whole height.

The capacity of the reservoir formed by this dam is approximately 5 million cub. meters (6,500,000 cub. yds).

The surface of the hydrographic basin of the Boite torrent is about 410 km² (160 sq. miles). The dangerous floods, estimated at 700 m³ (910 cub. yds) per second are discharged by a spill-way and an outlet channel.

The cost price of this dam, without spill-way or accessory works, is 800,000 lires.

The Lumiei torrent dam at La Maina.

(Figs 10, 11 and 12, Pl. II)

By means of this important dam in the form of an arc, designed by the writer, a very narrow gorge, hollowed out of limestone, must be blocked to a total height of 85 meters (275 ft) creating a reservoir of about 20 million m³ (2,600,000 cub. yds) capacity.

The width of the gorge varies between 8 meters (8 3/4 yds) at the bottom and 70 meters (76 1/2 yds) at the top of the dam, which it was possible to plan with varying curve centers, accord-

ing to the principle laid down at the beginning of this note, so as to create as advantageous a work as possible.

The arc is 25 meters (72 ft) thick at the base and 3 meters (9.8 ft) thick at the summit. The total volume of the dam is thus about 35,000 m^3 (45,000 cub. yds) and its cost estimated at 1 million 200,000 lires.

The hydrographic basin of the Lumiei torrent has a surface of only 60 km^2 (23 sq. miles), and as the reservoir formed is of large capacity, little importance was attached to the quantity of water, which at the time of calamitous floods, will rise above the crowning-level of the dam and flow freely down the outer face of the work.

b) *Reinforced concrete dams.*

Concrete dams, the use of which has made considerable progress in the United States of America, have not found, to the knowlegde of the writer, any application in Italy, where the tendancy is decidedly in favour of the standard types of masonry-work which have been sanctioned by practice.

Thus, in a recent competition the Ferro-beton C° of Rome proposed, for the Cagliari aquaduct, a reinforced concrete dam with a maximum height of 18 meters (59 ft), of the Ambursen type (figs 13, 14 and 15. Pl. II), but though the plan was carefully studied it did not meet with a favourable reception.

A type of dam which is interesting because of its originality and deserves to be mentioned, called « divided load dam » (1), has been conceived by Mr. Pietro Rutenberg, Engineer of Genoa.

The Rutenberg system consists essentially in blocking the valley by means of several transverse parallel diaphragms of decreasing height from the inner side to the outer side, each one forming a reservoir.

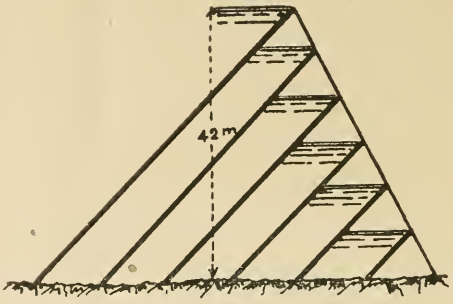
According to the inventor the principal advantages of this system are the following :

a) to diminish arbitrarily, to values that need not even be taken

(1) Houille blanche; September 1913. Les barrages à charge fractionnée, système P. Rutenberg. Monitore Tecnico, Anno XVIII, N° 24. Dighe di Sbarramento a carico frazionato Sistéma P. Rutenberg.

into account, the water-load whatever may be the high water level.

b) to reduce the danger of rupture of the dam and the corresponding immediate emptying of all the water stored in the lake to that compatible with a limited break, which can be easily repaired and only causing a slow discharge of the water.



Weir on the Rutenby system

For instance for a dam 40 meters high each maximum load can be reduced so as not to exceed 5 meters by forming the dam of 8 diaphragms of a decreasing height of 5 meters each.

The partitions formed with this system must, naturally, be consolidated by means of suitably adapted connecting pillars.

The inventor completed his system by placing special self-regulating devices, and safety diaphragms, thus avoiding the inconveniences which might arise from an excessive diminution of the level of the water in the partitions.

Mr. Rutenberg is of the opinion that dams built according to his system also offer great economical advantages; he calculated the volumes of material necessary for a divided-load dam of the same height as the Prelé dam built in America after the Ambursen type, and he found that his system allowed of realising an economy of about 40 % in volume per running meter over that of Ambursen.

Mr. Rutenberg has drawn up several plans for dams on his system, and we have reproduced on Pl. II, figs 16 and 17, the one which he worked out for the reservoir of Campomore, in the Malenco valley, for the Idra-Electrica C°. However no construction of this kind has yet been carried out.

The Brothers Damioli, engineers, presented to the Societa per le Forze Idrauliche della Maira, a short time ago, a plan for a reinforced concrete dam about 90 meters (98 1/2 yds) long and 8.50 meters (27.9 ft) high (Pl. II, figs 18 and 19).

This dam is planned so that the resultant of the acting forces falls at the middle of the base.

The Brothers Damoli also thought it necessary to provide against the inconveniences which might eventually arise through cracks forming in some of the panels through chemical or thermal deformations or through the sinking of the foundations; with this object they designed the dam with a double retaining partition, so that the possible inconveniences in question could be eliminated later on by filling the space between the two partitions with some plastic material, asphalte or tar.

By reason of difficulties, which have nothing to do with the design, it is also probable that this construction will not be carried out.

An interesting construction, which was carried out by Mr. Felice Damioli, Engineer (1), is that of a dam 7.30 meters (32.8 ft) high and about 140 meters (153 yds) long to form a reservoir with a total capacity of about 20,000 m³ (26,000 sq. yds) to supply force to the Adamello Hydroelectric Station.

The reason for deciding on a reinforced concrete dam here, was that by this means it was possible to raise the capacity of the basin to its maximum, only a small surface being available for the establishment of this work.

The dam (Pl. II, figs 20 and 21) is formed of 140 cells superposed in three rows, and, thanks to this construction, the water contained in the cells exercices its pressure on the bottom and thus contributes to the stability of the work, whilst its total volume of about 4,000 m³ (5,200 cub. yds) is a useful volume for the object that the reservoir must fulfil, its capacity being thus increased 25 %.

The question of stability was resolved in such a way that : supposing the dam be sectioned at any point, each portion can

(1) Monitore Tecnico, Anno 1919, N° 27, 35. Ing. Nino Sacerdoti-Gli Impianti Idro-Elettrici del Poglia. Schweizerische Banzeitung. Vol. LVII, N° 1-4-1911. L. Rodel. Das Wasserkraftwerk Adamello.

resist independently of the adjacent portions, and that the total resistance may not be influenced by the inevitable cracks due to chemical or thermal contractions of the materials employed.

In order to avoid the influence of the counter-pressure of the water, drainage was provided for between the foundations and the reinforced concrete compartment forming the dam.

This work was built in 100 days and began working in 1910, since when it has continued without any inconveniences.

The conclusions that may be drawn from this study can be summed up as follows :

1° *Arched dams will still find, as they have already done, numerous applications in our country, this form being justified by the nature of the local conditions which are essentially favourable to its use.*

2° *As regards reinforced concrete dams, there still reigns some uncertainty on the technical side and also as regards the types, which, sanctioned by long experience, can banish the hesitation of those who are responsible for works of this importance.*

A. FORTI, Engineer.

Translated by E. Leeds. The Live School, 42, rue de l'Enseignement, Brussels.

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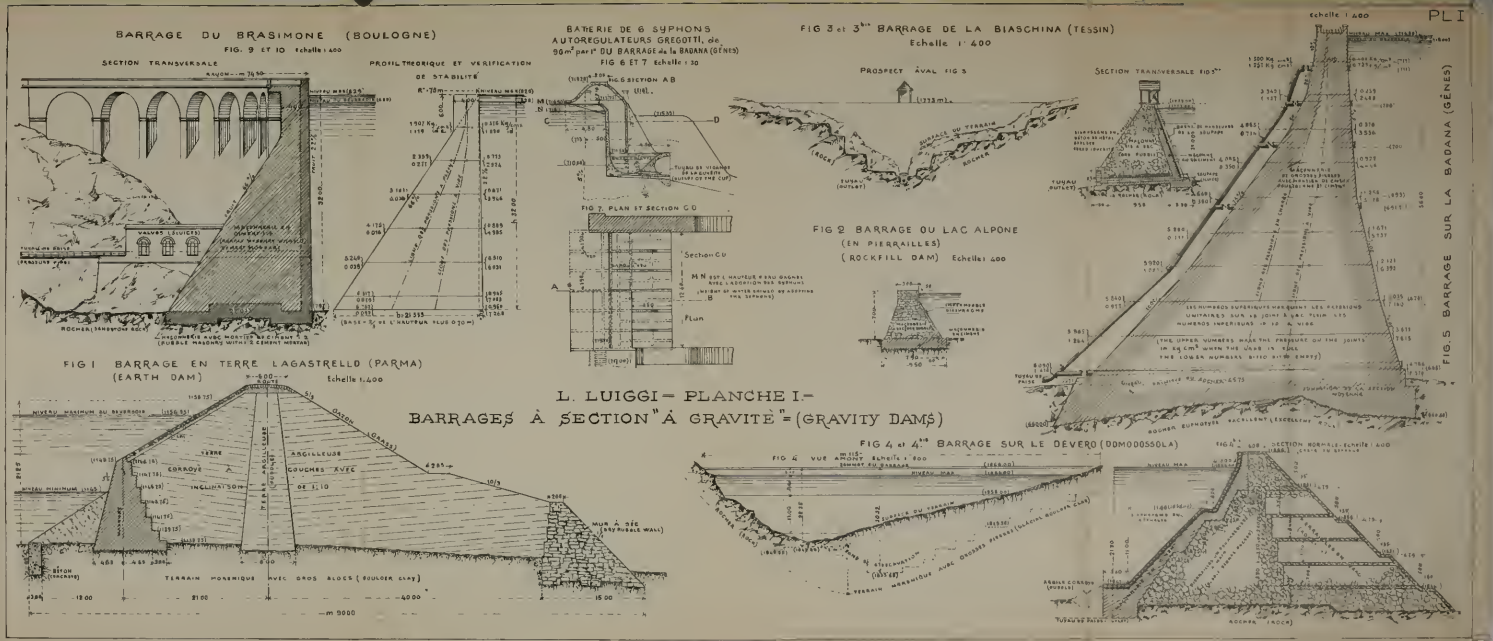
Association Internationale Permanente
des
Congrès de Navigation.

Navigation intérieure.

Barrages de réservoirs
Conditions d'établissement et d'emploi.
Progrès réalisés dans leur construction.

Rapport
par
Luiggi, Luig.
et
Torti, Ingés

Planche I


PL I
BARRAGE DU BRASIMONE (BOULOGNE)
FIG. 9 ET 10 Echelle 1:400
SECTION TRANSVERSALE
PROFIL THEORIQUE ET VERIFICATION DE STABILITÉ
BATERIE DE 6 SYPHONS AUTOREGULATEURS GREGOTTI, de 90m² par m² DU BARRAGE de la BADANA (GÊNES)
FIG 6 ET 7 Echelle 1:50
FIG 6 SECTION AB
FIG 7. PLAN ET SECTION CD
FIG 3 et 3bis BARRAGE DE LA BIASCHINA (TESSIN)
Echelle 1:400
PROSPECT AVAL FIG 3
SECTION TRANSVERSALE FIG 3bis
FIG 2 BARRAGE OU LAC ALPONE (EN PIERRAILLES) (ROCKFILL DAM) Echelles 400
FIG 5 BARRAGE SUR LA BADANA (GÊNES)
FIG 1 BARRAGE EN TERRE LAGASTRELLO (PARMA) (EARTH DAM) Echelle 1:400
L. LUIGGI – PLANCHE I.–
BARRAGES À SECTION "À GRAVITÉ" = (GRAVITY DAMS)
FIG 4 et 4bis BARRAGE SUR LE DEVERO (DOMODOSSOLA)
FIG 4 VUE AMONT Echelle 1:800
FIG 4bis SECTION NORMALE Echelle 1:400

7- VUE

EMBERG

RANSVERSALE
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– PROJET DAMI

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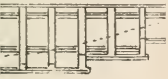

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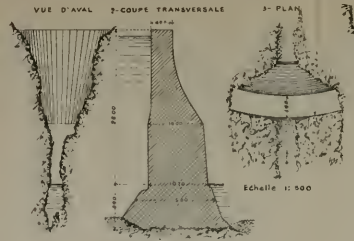
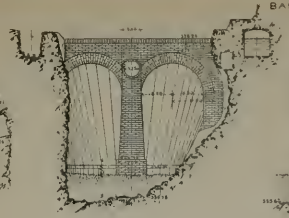
par
Luiggi, Luigi
et
Jorti, Angelo.

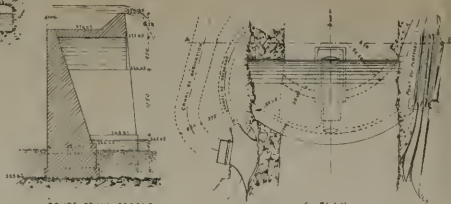
Planche II

BARRAGE DU TORRE A CROSIS

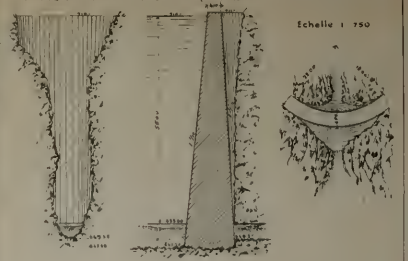




BARRAGE DU CISMON À PONTE SERRA
Echelle 1:750

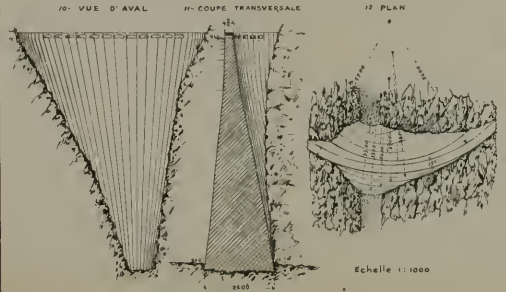


BARRAGE DU BOITE AU PONTE POCROCE

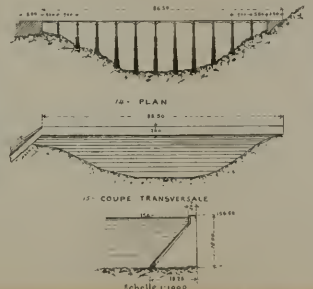


A. FORTI - PLANCHE II. BARRAGES EN VOUTE ET EN CIMENT ARMÉ

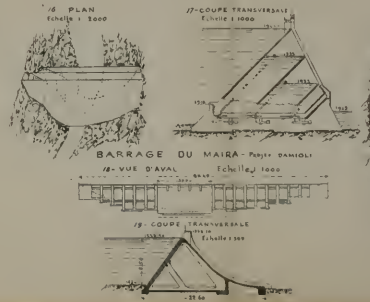
BARRAGE DU LUMIEI À LA MAINA



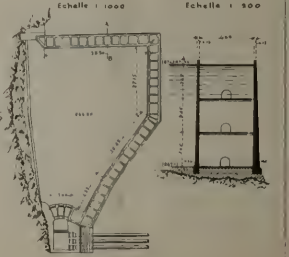
BARRAGE POUR CAGLIARI
(SOC^TE FERROBETON)



BARRAGE SYSTEM RUTEMBERG
POUR LE LAC CAMPO MORO



RÉSERVOIR DE L'USINE ADAMELLO



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